The development of a MUAC-for-height reference, including a comparison to other nutritional status screening indicators

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Mid-upper-arm circumference (MUAC) based on a single cut-off value for all the children less than 5 years of age has been used for many years as an alternative nutritional status index for children during famines or refugee crises, and as an additional screening tool in nonemergencies. However, it has recently been questioned whether MUAC is age- and sex-independent. After reviewing the scientific evidence underlying the use and interpretation of MUAC, a WHO Expert Committee recommended a new MUAC-for-age reference for under-5-year-olds. In some settings, however, it is difficult to assess a child's age and in such circumstances MUAC-for-height may be a good alternative. The height-based QUAC stick is a simple means of adjusting MUAC cut-offs according to height, and the MUAC-for-height reference and the construction and use of the QUAC stick are described in this article. Described also is the use of the receiver operating characteristic (ROC) curve method to evaluate the performance of MUAC, MUAC-for-age, and MUAC-for-height in screening malnourished children.

Introduction

Mid-upper-arm circumference (MUAC) has been used for many years as an alternative index of nutritional status of children in situations, such as famines or refugee crises, where the collection of height and weight measurements is difficult (1–4). Also MUAC has been used as an additional screening tool in non-emergency situations because of its power to predict childhood mortality (5–7).

A single MUAC cut-off value (generally 12.5 cm or 13.0 cm), which is based on observations on normal, well-fed Polish children in the early 1960s (1, 8, 9), has been used over the last 30 years for children under 5 years of age. However, the idea that MUAC is age- and sex-independent in young children has recently been questioned, and it has been suggested that MUAC Z-scores, which adjust for differences by age and sex, are a more useful indicator of nutritional status (10, 11). A WHO Expert Committee has recommended a new MUAC-for-age reference for children aged 6–60 months (12, 13).

In order to facilitate field work to assess nutritional status rapidly, a method was developed in the

1960s to relate the measured MUAC to the child's height using a special measuring stick — the QUAC stick (*Q*uaker *A*rm *C*ircumference measuring stick) (14, 15). The QUAC stick method, which measures the arm circumference at the mid-upper level and compares this value with the child's height, is simple, inexpensive, easy to use, independent of correct age, and fairly reliable (16–21). However, the QUAC stick reference data that are currently being used are derived from separate sets of MUAC data based on well-nourished Polish children (9) and from height data based on healthy West Nigerian village children (14, 18) or on country-specific data (19). In this article we provide a MUAC-for-height reference for international use based on the same set of data recommended by a WHO Expert Committee for use as a MUAC-for-age reference (12, 13). We also propose a "standard" QUAC stick, which facilitates comparison of data between countries.

Methods

To develop the MUAC-for-height growth reference, we used the growth data for children aged 6 months to <10 years from the sample collected for the first and second National Health and Nutrition Examination Surveys for the USA (NHANES I, NHANES II) (22, 23). These two surveys were conducted by the National Center for Health Statistics (NCHS) to provide data for representative samples of the civilian non-institutionalized population in the USA. NHANES I examined persons aged 1–74 years over

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the period 1971–74, and NHANES II those aged 6 months to 74 years over the period 1976–80. Detailed descriptions of the samples selected have been published elsewhere (22, 23). There were a total of 23 808 MUAC measurements from a combined NHANES I and NHANES II sample of children aged 6 months to less than 10 years.

To estimate the median MUAC values over a small range of heights, we used the exploratory data analysis (EDA) line-fitting method ("three-group resistant line") (24). The data were divided into three subgroups based on height, the median MUAC calculated for each subgroup, and a line fitted through these three summary medians. We used 6-cm wide height windows and subdivided these into 2-cm wide subgroups; for example, the MUAC data for 77.0–82.9 cm were divided into the subgroups 77.0–78.9 cm, 79.0–80.9 cm, and 81.0–82.9 cm and the median MUAC was calculated for each subgroup. A line was then fitted through the medians and the predicted MUAC determined at 80.0 cm (the midpoint of the height windows) (see Fig. 1). This procedure was repeated for every 6-cm window of height, with midpoints ranging from 65.0 to 145.0 cm calculated at 1.0-cm intervals (i.e. a total of 81 times). A smoothed median curve was then fitted through the 81 predicted medians using a 5th degree polynomial.

Using the smoothed median curve, we calculated the residuals of each data point and the standard deviation (SD) for each 6-cm window about the smoothed median curve. The standard deviation was calculated as the square root of the mean squared error. Because the MUAC distribution is skewed, we calculated the upper SD separately using only the positive residuals and the lower SD using only the negative residuals. A curve was then fitted to the 81 upper and lower SDs using a cubic polynomial.

Three sets of MUAC-for-height curves were developed, one for boys, one for girls, and one for both sexes combined. The SD curves were similar for boys and girls; thus, to improve the precision, the SD curves for both sexes combined were used for all three sets of reference curves.

In order to eliminate any discrepancy caused by recumbent length versus standing height measurements for each of the references across height, all the recumbent lengths <85 cm were adjusted to standing heights by subtracting 0.4 cm from them. This 0.4-cm adjustment was based on the difference between length and height measurements in the NHANES II data for children aged 24–35 months who had both measurements taken. After the smoothing procedure, for the final reference data, we reconverted height <85 cm to length by adding 0.4 cm. As a result, the measurement protocols used to create the reference are equivalent to standard procedures developed to measure children in clinic and field settings.

Growth data from Sri Lanka (25), Nepal (26), Togo (27), and Malawi (28) were used to evaluate the performance of the indicators of MUAC, MUAC-for-age, and MUAC-for-height, using weight-for-height < -2 Z-score as the "gold standard" for identifying malnourished children. The Sri Lanka (1975–76), Nepal (1975), and Togo (1976–1977) data sets were obtained form national cross-sectional surveys supported by the Centers for Disease Control and Prevention (CDC) and the U.S. Agency for International Development (USAID); the sample size for children aged 6–59 months in the three surveys was 13 469, 6579, and 6120, respectively. The Malawi Maternal and Child Nutrition (MMCN) Study is a 3-year (1986–89) longitudinal survey of a total of 3009 records of children aged 6–59 months (28); for this purpose, we used receiver operating characteristic (ROC) curves (29), constructed by plotting the sensitivity against the value of 1-specificity. In general, the further the ROC curve deviates from the chance line (the line connecting the two corners of the plot frame), the better the indicator's performance.

Fig. 1. Illustration of the exploratory data analysis (EDA) procedure. Data points (+). Data summary medians (•) and a fitted line for the 6-cm window used to obtain the predicted MUAC value at the mid-point of the height window.
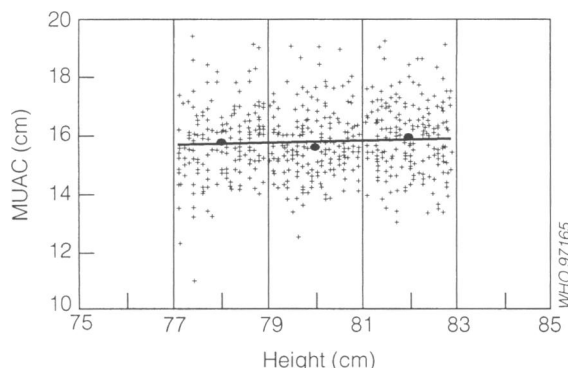

Results

Table 1 presents MUAC-for-height reference data for boys, girls, and both sexes combined for 6–119-month-old children in NHANES I and NHANES II

Table 1: **Mid-upper-arm-circumference (MUAC)-for-length or height reference data**

Length/height[a] (cm)	Boys			Combined sexes			Girls			Length/height[a] (cm)
	Median	−2 SD	−3 SD	Median	−2 SD	−3 SD	Median	−2 SD	−3 SD	
65.0	14.6	12.7	11.7	14.3	12.4	11.5	14.0	12.1	11.2	65.0
65.5	14.7	12.7	11.8	14.4	12.5	11.5	14.1	12.2	11.2	65.5
66.0	14.7	12.8	11.8	14.5	12.5	11.6	14.2	12.3	11.3	66.0
66.5	14.8	12.8	11.8	14.5	12.6	11.6	14.3	12.3	11.3	66.5
67.0	14.9	12.9	11.9	14.6	12.6	11.6	14.4	12.4	11.4	67.0
67.5	14.9	12.9	11.9	14.7	12.7	11.7	14.4	12.4	11.4	67.5
68.0	15.0	12.9	11.9	14.7	12.7	11.7	14.5	12.5	11.5	68.0
68.5	15.0	13.0	12.0	14.8	12.8	11.7	14.6	12.6	11.5	68.5
69.0	15.1	13.0	12.0	14.9	12.8	11.8	14.7	12.6	11.6	69.0
69.5	15.1	13.0	12.0	14.9	12.8	11.8	14.7	12.7	11.6	69.5
70.0	15.1	13.1	12.0	15.0	12.9	11.8	14.8	12.7	11.7	70.0
70.5	15.2	13.1	12.0	15.0	12.9	11.9	14.8	12.8	11.7	70.5
71.0	15.2	13.1	12.1	15.1	13.0	11.9	14.9	12.8	11.7	71.0
71.5	15.3	13.1	12.1	15.1	13.0	11.9	15.0	12.8	11.8	71.5
72.0	15.3	13.2	12.1	15.2	13.0	12.0	15.0	12.9	11.8	72.0
72.5	15.3	13.2	12.1	15.2	13.1	12.0	15.1	12.9	11.8	72.5
73.0	15.4	13.2	12.1	15.2	13.1	12.0	15.1	13.0	11.9	73.0
73.5	15.4	13.2	12.2	15.3	13.1	12.0	15.2	13.0	11.9	73.5
74.0	15.4	13.3	12.2	15.3	13.1	12.1	15.2	13.0	11.9	74.0
74.5	15.5	13.3	12.2	15.4	13.2	12.1	15.2	13.1	12.0	74.5
75.0	15.5	13.3	12.2	15.4	13.2	12.1	15.3	13.1	12.0	75.0
75.5	15.5	13.3	12.2	15.4	13.2	12.1	15.3	13.1	12.0	75.5
76.0	15.6	13.4	12.2	15.5	13.3	12.2	15.4	13.2	12.1	76.0
76.5	15.6	13.4	12.3	15.5	13.3	12.2	15.4	13.2	12.1	76.5
77.0	15.6	13.4	12.3	15.5	13.3	12.2	15.4	13.2	12.1	77.0
77.5	15.6	13.4	12.3	15.6	13.3	12.2	15.5	13.3	12.1	77.5
78.0	15.7	13.4	12.3	15.6	13.4	12.2	15.5	13.3	12.2	78.0
78.5	15.7	13.4	12.3	15.6	13.4	12.3	15.6	13.3	12.2	78.5
79.0	15.7	13.5	12.3	15.6	13.4	12.3	15.6	13.3	12.2	79.0
79.5	15.7	13.5	12.4	15.7	13.4	12.3	15.6	13.4	12.2	79.5
80.0	15.8	13.5	12.4	15.7	13.4	12.3	15.6	13.4	12.3	80.0
80.5	15.8	13.5	12.4	15.7	13.5	12.3	15.7	13.4	12.3	80.5
81.0	15.8	13.5	12.4	15.8	13.5	12.4	15.7	13.4	12.3	81.0
81.5	15.8	13.6	12.4	15.8	13.5	12.4	15.7	13.5	12.3	81.5
82.0	15.9	13.6	12.4	15.8	13.5	12.4	15.8	13.5	12.3	82.0
82.5	15.9	13.6	12.5	15.8	13.6	12.4	15.8	13.5	12.4	82.5
83.0	15.9	13.6	12.5	15.9	13.6	12.4	15.8	13.5	12.4	83.0
83.5	15.9	13.6	12.5	15.9	13.6	12.5	15.8	13.6	12.4	83.5
84.0	15.9	13.7	12.5	15.9	13.6	12.5	15.9	13.6	12.4	84.0
84.5	16.0	13.7	12.5	15.9	13.6	12.5	15.9	13.6	12.5	84.5
85.0	16.0	13.7	12.5	15.9	13.6	12.5	15.9	13.6	12.5	85.0
85.5	16.0	13.7	12.6	16.0	13.7	12.5	15.9	13.6	12.5	85.5
86.0	16.0	13.7	12.6	16.0	13.7	12.5	15.9	13.7	12.5	86.0
86.5	16.0	13.7	12.6	16.0	13.7	12.6	16.0	13.7	12.5	86.5
87.0	16.1	13.8	12.6	16.0	13.7	12.6	16.0	13.7	12.5	87.0
87.5	16.1	13.8	12.6	16.0	13.7	12.6	16.0	13.7	12.6	87.5
88.0	16.1	13.8	12.6	16.1	13.8	12.6	16.0	13.7	12.6	88.0
88.5	16.1	13.8	12.7	16.1	13.8	12.6	16.1	13.8	12.6	88.5
89.0	16.1	13.8	12.7	16.1	13.8	12.7	16.1	13.8	12.6	89.0
89.5	16.2	13.9	12.7	16.1	13.8	12.7	16.1	13.8	12.7	89.5
90.0	16.2	13.9	12.7	16.2	13.9	12.7	16.1	13.8	12.7	90.0
90.5	16.2	13.9	12.8	16.2	13.9	12.7	16.2	13.8	12.7	90.5
91.0	16.2	13.9	12.8	16.2	13.9	12.7	16.2	13.9	12.7	91.0
91.5	16.3	14.0	12.8	16.2	13.9	12.8	16.2	13.9	12.7	91.5
92.0	16.3	14.0	12.8	16.3	13.9	12.8	16.2	13.9	12.8	92.0

(*Table 1, continued*)

Length/height[a] (cm)	Boys			Combined sexes			Girls			Length/height[a] (cm)
	Median	−2 SD	−3 SD	Median	−2 SD	−3 SD	Median	−2 SD	−3 SD	
92.5	16.3	14.0	12.9	16.3	14.0	12.8	16.2	13.9	12.8	92.5
93.0	16.3	14.0	12.9	16.3	14.0	12.8	16.3	14.0	12.8	93.0
93.5	16.4	14.1	12.9	16.3	14.0	12.9	16.3	14.0	12.8	93.5
94.0	16.4	14.1	12.9	16.4	14.0	12.9	16.3	14.0	12.8	94.0
94.5	16.4	14.1	13.0	16.4	14.1	12.9	16.3	14.0	12.9	94.5
95.0	16.4	14.1	13.0	16.4	14.1	12.9	16.4	14.1	12.9	95.0
95.5	16.5	14.2	13.0	16.4	14.1	13.0	16.4	14.1	12.9	95.5
96.0	16.5	14.2	13.0	16.5	14.1	13.0	16.4	14.1	12.9	96.0
96.5	16.5	14.2	13.1	16.5	14.2	13.0	16.4	14.1	13.0	96.5
97.0	16.6	14.2	13.1	16.5	14.2	13.0	16.5	14.1	13.0	97.0
97.5	16.6	14.3	13.1	16.5	14.2	13.1	16.5	14.2	13.0	97.5
98.0	16.6	14.3	13.1	16.6	14.2	13.1	16.5	14.2	13.0	98.0
98.5	16.6	14.3	13.2	16.6	14.3	13.1	16.5	14.2	13.1	98.5
99.0	16.7	14.3	13.2	16.6	14.3	13.1	16.6	14.3	13.1	99.0
99.5	16.7	14.4	13.2	16.6	14.3	13.2	16.6	14.3	13.1	99.5
100.0	16.7	14.4	13.2	16.7	14.4	13.2	16.6	14.3	13.1	100.0
100.5	16.8	14.4	13.3	16.7	14.4	13.2	16.7	14.3	13.2	100.5
101.0	16.8	14.5	13.3	16.7	14.4	13.2	16.7	14.4	13.2	101.0
101.5	16.8	14.5	13.3	16.8	14.4	13.3	16.7	14.4	13.2	101.5
102.0	16.9	14.5	13.4	16.8	1.45	13.3	16.7	14.4	13.2	102.0
102.5	16.9	14.6	13.4	16.8	14.5	13.3	16.8	14.4	13.3	102.5
103.0	16.9	14.6	13.4	16.9	14.5	13.4	16.8	14.5	13.3	103.0
103.5	16.9	14.6	13.4	16.9	14.6	13.4	16.8	14.5	13.3	103.5
104.0	17.0	14.6	13.5	16.9	14.6	13.4	16.9	14.5	13.4	104.0
104.5	17.0	14.7	13.5	17.0	14.6	13.4	16.9	14.6	13.4	104.5
105.0	17.0	14.7	13.5	17.0	14.6	13.5	16.9	14.6	13.4	105.0
105.5	17.1	14.7	13.6	17.0	14.7	13.5	17.0	14.6	13.4	105.5
106.0	17.1	14.8	13.6	17.1	14.7	13.5	17.0	14.6	13.5	106.0
106.5	17.1	14.8	13.6	17.1	14.7	13.6	17.0	14.7	13.5	106.5
107.0	17.2	14.8	13.6	17.1	14.8	13.6	17.1	14.7	13.5	107.0
107.5	17.2	14.8	13.7	17.2	14.8	13.6	17.1	14.7	13.6	107.5
108.0	17.3	14.9	13.7	17.2	14.8	13.6	17.1	14.8	13.6	108.0
108.5	17.3	14.9	13.7	17.2	14.9	13.7	17.2	14.8	13.6	108.5
109.0	17.3	14.9	13.7	17.3	14.9	13.7	17.2	14.8	13.6	109.0
109.5	17.4	15.0	13.8	17.3	14.9	13.7	17.3	14.9	13.7	109.5
110.0	17.4	15.0	13.8	17.4	15.0	13.8	17.3	14.9	13.7	110.0
110.5	17.4	15.0	13.8	17.4	15.0	13.8	17.3	14.9	13.7	110.5
111.0	17.5	15.1	13.9	17.4	15.0	13.8	17.4	15.0	13.8	111.0
111.5	17.5	15.1	13.9	17.5	15.0	13.8	17.4	14.0	13.8	111.5
112.0	17.5	15.1	13.9	17.5	15.1	13.9	17.5	15.0	13.8	112.0
112.5	17.6	15.1	13.9	17.6	15.1	13.9	17.5	15.1	13.9	112.5
113.0	17.6	15.2	14.0	17.6	15.1	13.9	17.6	15.1	13.9	113.0
113.5	17.7	15.2	14.0	17.6	15.2	14.0	17.6	15.2	13.9	113.5
114.0	17.7	15.2	14.0	17.7	15.2	14.0	17.7	15.2	14.0	114.0
114.5	17.7	15.3	14.0	17.7	15.2	14.0	17.7	15.2	14.0	114.5
115.0	17.8	15.3	14.0	17.8	15.3	14.0	17.8	15.3	14.0	115.0
115.5	17.8	15.3	14.1	17.8	15.3	14.1	17.8	15.3	14.1	115.5
116.0	17.9	15.4	14.1	17.9	15.3	14.1	17.9	15.3	14.1	116.0
116.5	17.9	15.4	14.1	17.9	15.4	14.1	17.9	15.4	14.1	116.5
117.0	18.0	15.4	14.1	18.0	15.4	14.1	18.0	15.4	14.1	117.0
117.5	18.0	15.4	14.2	18.0	15.4	14.2	18.0	15.5	14.2	117.5
118.0	18.0	15.5	14.2	18.1	15.5	14.2	18.1	15.5	14.2	118.0
118.5	18.1	15.5	14.2	18.1	15.5	14.2	18.1	15.5	14.2	118.5
119.0	18.1	15.5	14.2	18.2	15.6	14.3	18.2	15.6	14.3	119.0
119.5	18.2	15.6	14.2	18.2	15.6	14.3	18.2	15.6	14.3	119.5

(*Table 1, continued*)

Length/ height[a] (cm)	Boys			Combined sexes			Girls			Length/ height[a] (cm)
	Median	−2 SD	−3 SD	Median	−2 SD	−3 SD	Median	−2 SD	−3 SD	
120.0	18.2	15.6	14.3	18.3	15.6	14.3	18.3	15.7	14.3	120.0
120.5	18.3	15.6	14.3	18.3	15.7	14.3	18.4	15.7	14.4	120.5
121.0	18.3	15.6	14.3	18.4	15.7	14.4	18.4	15.7	14.4	121.0
121.5	18.4	15.7	14.3	18.4	15.7	14.4	18.5	15.8	14.4	121.5
122.0	18.4	15.7	14.3	18.5	15.8	14.4	18.5	15.8	14.5	122.0
122.5	18.5	15.7	14.4	18.5	15.8	14.4	18.6	15.9	14.5	122.5
123.0	18.5	15.8	14.4	18.6	15.8	14.5	18.7	15.9	14.5	123.0
123.5	18.6	15.8	14.4	18.6	15.9	14.5	18.7	16.0	14.6	123.5
124.0	18.6	15.8	14.4	18.7	15.9	14.5	18.8	16.0	14.6	124.0
124.5	18.7	15.8	14.4	18.8	15.9	14.5	18.9	16.1	14.6	124.5
125.0	18.7	15.9	14.5	18.8	16.0	14.6	18.9	16.1	14.7	125.0
125.5	18.8	15.9	14.5	18.9	16.0	14.6	19.0	16.1	14.7	125.5
126.0	18.8	15.9	14.5	19.0	16.1	14.6	19.1	16.2	14.7	126.0
126.5	18.9	16.0	14.5	19.0	16.1	14.6	19.2	16.2	14.8	126.5
127.0	18.9	16.0	14.5	19.1	16.1	14.7	19.2	16.3	14.8	127.0
127.5	19.0	16.0	14.5	19.2	16.2	14.7	19.3	16.3	14.8	127.5
128.0	19.1	16.1	14.6	19.2	16.2	14.7	19.4	16.4	14.9	128.0
128.5	19.1	16.1	14.6	19.3	16.3	14.7	19.5	16.4	14.9	128.5
129.0	19.2	16.1	14.6	19.4	16.3	14.8	19.5	16.5	14.9	129.0
129.5	19.3	16.2	14.6	19.4	16.3	14.8	19.6	16.5	15.0	129.5
130.0	19.3	16.2	14.6	19.5	16.4	14.8	19.7	16.6	15.0	130.0
130.5	19.4	16.2	14.6	19.6	16.4	14.9	19.8	16.6	15.1	130.5
131.0	19.5	16.3	14.7	19.7	16.5	14.9	19.9	16.7	15.1	131.0
131.5	19.5	16.3	14.7	19.8	16.5	14.9	20.0	16.7	15.1	131.5
132.0	19.6	16.3	14.7	19.8	16.6	14.9	20.1	16.8	15.2	132.0
132.5	19.7	16.4	14.7	19.9	16.6	15.0	20.2	16.8	15.2	132.5
133.0	19.8	16.4	14.7	20.0	16.7	15.0	20.2	16.9	15.2	133.0
133.5	19.8	16.5	14.8	20.1	16.7	15.0	20.3	17.0	15.3	133.5
134.0	19.9	16.5	14.8	20.2	16.8	15.0	20.4	17.0	15.3	134.0
134.5	20.0	16.5	14.8	20.3	16.8	15.1	20.5	17.1	15.3	134.5
135.0	20.1	16.6	14.8	20.4	16.9	15.1	20.6	17.1	15.4	135.0
135.5	20.2	16.6	14.9	20.5	16.9	15.1	20.7	17.2	15.4	135.5
136.0	20.3	16.7	14.9	20.6	17.0	15.2	20.8	17.2	15.5	136.0
136.5	20.4	16.7	14.9	20.7	17.0	15.2	20.9	17.3	15.5	136.5
137.0	20.5	16.8	14.9	20.8	17.1	15.2	21.1	17.4	15.5	137.0
137.5	20.5	16.8	15.0	20.9	17.1	15.3	21.2	17.4	15.6	137.5
138.0	20.7	16.9	15.0	21.0	17.2	15.3	21.3	17.5	15.6	138.0
138.5	20.8	16.9	15.0	21.1	17.2	15.3	21.4	17.6	15.7	138.5
139.0	20.9	17.0	15.0	21.2	17.3	15.4	21.5	17.6	15.7	139.0
139.3	21.0	17.0	15.1	21.3	17.4	15.4	21.6	17.7	15.7	139.5
140.0	21.1	17.1	15.1	21.4	17.4	15.4	21.7	17.8	15.8	140.0
140.5	21.2	17.2	15.2	21.5	17.5	15.5	21.9	17.8	15.8	140.5
141.0	21.3	17.2	15.2	21.7	17.6	15.5	22.0	17.9	15.9	141.0
141.5	21.5	17.3	15.2	21.8	17.6	15.6	22.1	18.0	15.9	141.5
142.0	21.6	17.4	15.3	21.9	17.7	15.6	22.2	18.0	15.9	142.0
142.5	21.7	17.5	15.3	22.0	17.8	15.7	22.4	18.1	16.0	142.5
143.0	21.9	17.5	15.4	22.2	17.9	15.7	22.5	18.2	16.0	143.0
143.5	22.0	17.6	15.4	22.3	17.9	15.8	22.7	18.3	16.1	143.5
144.0	22.1	17.7	15.5	22.5	18.0	15.8	22.8	18.4	16.1	144.0
144.5	22.3	17.8	15.5	22.6	18.1	15.9	22.9	18.4	16.2	144.5
145.0	22.4	17.9	15.6	22.8	18.2	15.9	23.1	18.5	16.2	145.0

[a] Length below 85 cm, height ⩾85 cm.

of height 65–145 cm. Because of sample size limitations, the reference data do not include children of height <65 cm or >145 cm. Fig. 2–4 provide the MUAC-for-height growth charts based on the data in Table 1, with curves representing the median and 1.0, 2.0, 3.0, and 4.0 SD values above and below the median. These plots exhibit a very small disjunction (about 0.01 cm in MUAC) for the recumbent length and standing height at 85 cm. Although the height-specific curves represent most of the variation related to the fixed cut-off, there are also significant differences between boys and girls of height 65.0–80.0 cm and 120.0–145.0 cm.

Fig. 2. MUAC-for-height reference curves for boys of height 65–145 cm.
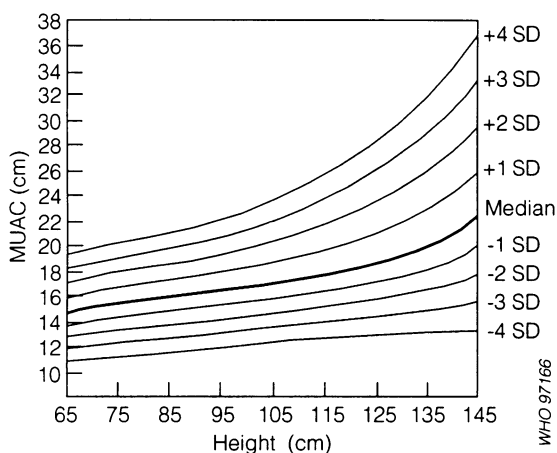
Fig. 3. MUAC-for-height reference curves for girls of height 65–145 cm.
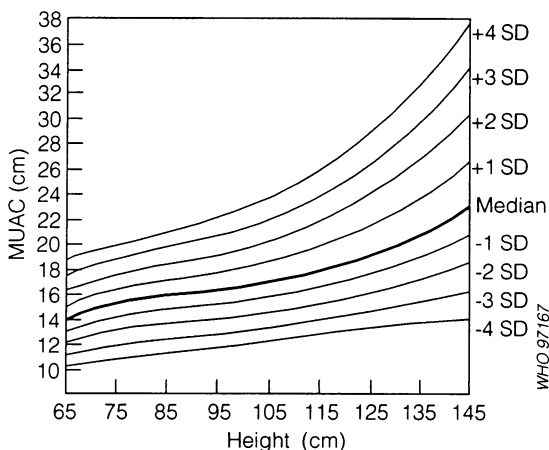
Fig. 4. MUAC-for-height reference curves for both sexes combined for height 65–145 cm.
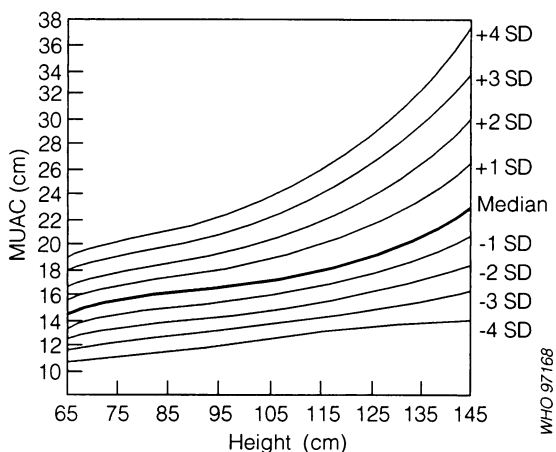
The SAS (Statistical Analysis System) code used to calculate the median curve and upper and lower standard deviation curves is shown in Annex 1. Using this code with their own data, readers can easily assign Z-scores to each child.

Fig. 5 compares the results obtained using ROC curves of MUAC, MUAC-for-age, and MUAC-for-

Fig. 5. Comparison of the ability of the receiver operating characteristic (ROC) curves of MUAC-for-age and MUAC-for-height to detect malnourished children (weight-for-height < 2 SD) for Sri Lankan children aged 6–59 months, 1975–76. (The diagonal is the chance line for the ROC curve).
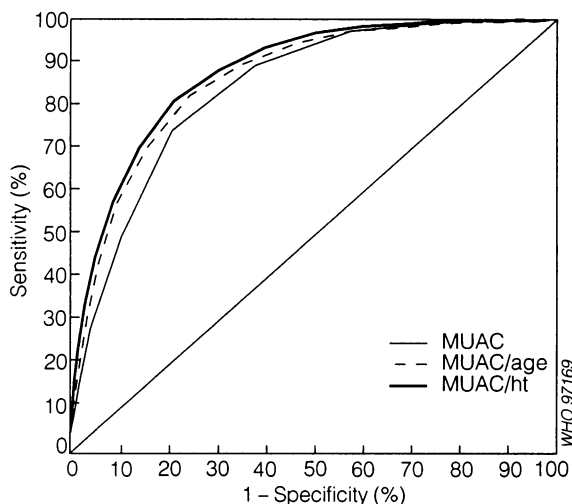
height to detect malnourished Sri Lankan children aged 6–59 months. MUAC-for-height and MUAC-for-age had better sensitivity and specificity than MUAC based on a fixed cut-off for screening children for malnutrition. A similar pattern for the ROC curves for these three indicators was obtained using nutrition survey data from Nepal and Togo as well as the Malawi longitudinal study data (results available on request).

Discussion

In this article, we have reported a reference set of curves for MUAC-for-height and demonstrated that the MUAC-for-height and MUAC-for-age Z-scores are better predictors of weight-for-height than either MUAC based on a fixed cut-off. MUAC-for-height has certain advantages over weight-for-height in emergency or refugee situations: first, it does not require the use of cumbersome scales; second, it is less influenced by errors in measuring height. For example, consider a boy whose true height, weight, and MUAC are 100.0 cm, 12.6 kg, and 14.1 cm, respectively; his weight-for-height Z-score is −2.29 based on the current NCHS/WHO international growth reference (30) and MUAC-for-height Z-score is −2.29, based on the MUAC-for-height reference we have developed in this article. Under emergency conditions it can be difficult to find a good, completely flat measuring platform with a vertical wall behind it. Under such conditions, or if the height is measured carelessly and is recorded, for example, 3 cm below the true value, the weight-for-height Z-score increases to −1.81; in contrast, the MUAC-for-height Z-score (−2.15) hardly changes. In reality, it is more likely that the MUAC measurements will be inaccurate, because of failure to identify correctly the mid-point of the upper arm, that the arm was flaccid, or that the tape was pulled too tightly or not tightly enough.

In developing the MUAC-for-height reference, we adjusted the recumbent length to standing height. However, the difference in MUAC between recumbent length and standing height at 85 cm is very small (ca. 0.01 cm) and has no clinical significance. In practical terms, this means that it is of no consequence whether the measurement is recumbent length or standing height. However, we recommend that children up to 85 cm be measured while they are lying down and those above 85 cm, standing to maintain consistency with the current international recommendations (12) and current length-for-age or weight-for-length protocols.

The QUAC stick technique can be used as a rapid method for determining levels of nutrition in large populations and as a screening tool for malnourished children (14, 15). It has many practical advantages, especially under difficult field conditions. A WHO-modified QUAC stick in described in Annex 2, including details of its construction and use. The reference data described in this article are meant to be used with the modified QUAC stick.

Résumé

Etablissement d'une valeur de référence pour le rapport MUAC/taille et comparaison avec d'autres indicateurs de l'état nutritionnel

Pour évaluer l'état nutritionnel des enfants en situation de crise, par exemple en cas de famine ou dans les camps de réfugiés, on utilise depuis longtemps le périmètre brachial à mi-hauteur (MUAC), en appliquant un seuil unique pour tous les enfants de moins de cinq ans. Cet indicateur est également utilisé comme moyen de dépistage complémentaire en dehors des situations d'urgence. Toutefois, la question se pose depuis quelque temps de savoir si le MUAC est bien indépendant de l'âge et du sexe. Après avoir passé en revue les bases scientifiques de l'utilisation et de l'interprétation du MUAC, un comité d'experts de l'OMS a recommandé une nouvelle référence pour le rapport MUAC/âge. Cependant, il est parfois difficile d'évaluer l'âge de l'enfant, et dans ces circonstances, le rapport MUAC/taille peut être une bonne solution. La règle QUAC offre un moyen simple d'ajuster le seuil du périmètre brachial en fonction de la taille; le présent article explique comment établir une référence MUAC/taille et fabriquer une règle QUAC. Il indique aussi comment utiliser la courbe ROC (receiver operating characteristic) pour évaluer la qualité du dépistage des enfants malnutris à l'aide des indicateurs MUAC, MUAC/âge et MUAC/taille.

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Annex 1

SAS code for MUAC-for-height(length) reference

HEIGHT is child's height/length (in cm), MUAC is child's mid-upper-arm circumference (in cm), and MUACHTZ is child's MUAC-for-height(length) Z-score.

```
IF HEIGHT GE 65 AND HEIGHT LE 145
THEN DO;
   IF SEX = "M" THEN
      MEDIAN = -127.85283 + 7.01912*
               (HEIGHT) - 0.13765*
               (HEIGHT)^2 + 1.34691E-03*
               (HEIGHT)^3 - 6.55082E-06*
               (HEIGHT)^4 + 1.27334E-08*
               (HEIGHT)^5;
   ELSE IF SEX = "F" THEN
      MEDIAN = -100.76669 + 5.11495*
               (HEIGHT) - 0.09007*
               (HEIGHT)^2 + 7.94219E-04*
               (HEIGHT)^3 - 3.51033E-06*
               (HEIGHT)^4 + 6.33942E-09*
               (HEIGHT)^5;
   ELSE IF SEX = . THEN
      MEDIAN = -114.30975 + 6.06703*
               (HEIGHT) - 0.11386*
               (HEIGHT)^2 + 1.07056E-03*
               (HEIGHT)^3 - 5.03058E-06*
               (HEIGHT)^4 + 9.53642E-09*
               (HEIGHT)^5;

   IF MUAC < MEDIAN THEN
      SD = -5.64795 + 0.21659*(HEIGHT) -
           2.30396E-03*(HEIGHT)^2 +
           8.18966E-06*(HEIGHT)^3;
   ELSE IF MUAC > MEDIAN THEN
      SD = 2.05049 - 0.01880*(HEIGHT) -
           1.38497E-05*(HEIGHT)^2 +
           1.51434E-06*(HEIGHT)^3;

   IF MUAC =. THEN MUACHTZ = 9.99; *for
MUAC missing values;
   ELSE MUACHTZ = (MUAC - MEDIAN)/
      SD;
END;
```

Annex 2

Construction and use of the modified QUAC stick

1. Construct a QUAC stick as shown in Fig. 1 from a piece of wood about 150cm long and 3 × 3cm in cross-section. On one face mark each 0.5cm, from 0 at the bottom up to 145cm near the top; write on it the height/length for each full cm. This equipment is convenient to measure height for children ≥85cm (for those <85cm the length should be measured on a measuring board). On one adjacent face, mark the corresponding reference values for median −2 SD of MUAC-for-height (see Table 1, main text); two sticks are preferable, one for boys and one for girls; otherwise, enter the values for sexes combined (see Table 1, main text). On the other face adjacent to the height measurement, enter the values for median −3 SD of the MUAC-for-height (see Table 1, main text).

2. Place the stick firmly and uprightly on a platform against a vertical wall. Have the child stand straight with his/her back flat against the height measure. Measure the height using a flat measuring board.

3. Measure the MUAC in mm. Note whether this value is below that given on the "median −3 SD" face; if below it, record as severe deficit; if above it, look on the "median −2 SD" face. If the measurement is below this, record as moderate deficit; if above it, record as no deficit. Thus, all children are identified as having severe, moderate or no deficit, in the same way as with weight-for-height.

Fig. 1. **The WHO-modified QUAC stick.**